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Calculating Moisture Content of 1000-Hour Timelag Fuels in Western Washington and Western Oregon

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Abstract

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A predictive model is presented to calculate moisture content of 1000-hour timelag fuels in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) logging slash in western Washington and western Oregon. The model is a modification of the 1000-hour fuel moisture model of the National Fire-Danger Rating System and requires daily measurements of precipitation duration, maximum and minimum relative humidities, and maximum and minimum temperatures. Comparison of measured and calculated fuel moisture contents showed good agreement. The model allows managers to accurately calculate fuel moisture values from weather variables for fuel reduction estimates. Current fire-weather stations provide adequate weather data for satisfactory operation of the 1000-hour fuel moisture model.

Keywords: Fuel moisture content, fire danger rating.

Summary

A moisture model (ADJ-Th) has been developed that estimates within ±5 percent the average fuel moisture content for 1000-hour timelag fuels in western Washington and western Oregon logging slash. It is a modification of the 1000-hour fuel moisture model of the National Fire-Danger Rating System (NFDR-Th), adjusted to represent west-side fuel types. The model allows fire managers to accurately calculate moisture content of large, woody fuels from weather variables for fuel reduction estimates.

Direct measurement on a given day showed considerable variation in moisture content between logs. Statistics indicate that to assure an error of less than ±5 percent, a minimum of 20 fuel moisture samples must be collected. The NFDR-Th underpredicted average measured fuel moisture content for west-side logging units and overpredicted rate of change in the drying cycle. The error resulted from internal coefficients developed for ponderosa pine (*Pinus ponderosa* Dougl.) being tested against western redcedar (*Thuja plicata* Donn) as a "worst case" fire-danger rating. By calculating a ratio between the measured and predicted fuel moisture values that were preceded by 7 days of dry weather, then varying the environmental coefficient, we adjusted the NFDR-Th to provide the accuracy needed for predicting fuel reduction.

Current fire-weather stations provide adequate weather data for satisfactory operation of the 1000-hour fuel moisture model.

Contents

Introduction

Scheduling prescribed fire to achieve desired effects depends on the ability to predict large-fuel consumption. Sandberg and Ottmar (1983) developed an algorithm for predicting diameter reduction of large, woody fuels in broadcast-burned logging slash in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region of western Washington and western Oregon. The algorithm requires an average moisture content of 1000-hour timelag fuels.[1]

The 1000-hour fuel moisture model of the National Fire-Danger Rating System (NFDR-Th) (Deeming and others 1977) was developed to calculate the moisture content of large, woody fuels. It has been tested successfully against a data set of measured fuel moisture values from western redcedar (*Thuja plicata* Donn) logs (Fosberg and others 1981). The model, however, cannot be applied accurately to the Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) slash common to units[2] in western Washington and western Oregon. Objectives of our study were to compare fuel-moisture calculations obtained from NFDR-Th with measured values, then to adjust the model to better represent those fuels.

This paper discusses the development and field evaluation of a regionally specific moisture model (ADJ-Th) (Ottmar 1980) that calculates a mean moisture content for woody material in the 3- to 9-inch-diameter size class of Douglas-fir and western hemlock logging slash in western Washington and western Oregon. The model, a modification of NFDR-Th, requires daily measurements of precipitation duration and maximum and minimum relative humidities and temperatures. A comparison test between fuel moisture contents calculated from offsite and onsite weather station data is also discussed.

Review of NFDR-Th

In 1978, an updated version of the 1972 National Fire-Danger Rating System was released, amending deficiencies noted by scientists and users. One amendment was the addition of large fuels (1000-hour timelag class) that responded to long-term drying. A component of this system is the fuel moisture model for 1000-hour timelag fuels, developed by Fosberg (1972).

Fuel moisture is the cumulative effect of past and present weather events. Fosberg describes the change through a series of numerical and analytical solutions of the Fickian diffusion equation (Fosberg and others 1981). The basic equation for fuel moisture change is:

$$m = m_o + (m_b - m_o)\,(1 - \zeta \exp(-\delta t/\tau)); \qquad (1)$$

where:

m = final fuel moisture,
m_o = initial fuel moisture,
m_b = 7-day average boundary condition,
ζ = environmental coefficient accounting for nonuniform moisture distribution inside the fuel and for environmental variations,
δt = time interval of actual moisture change, and
τ = timelag constant of the fuel.

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[1] Dead, woody fuels 3 to 9 inches in diameter.

[2] As used in this report, unit refers to a timber-harvested site with unburned logging slash.

To make equation (1) appropriate for predicting moisture content of 1000-hour timelag fuels, Fosberg and others (1981) substituted the following:

δ = 0.82,
δt = 7×24 hours (averaging the boundary condition over 7 days), and
τ = 1000 hours.

Hence, equation (1) becomes:

$$m = m_o + (m_b - m_o)\,(1 - 0.82\,\exp(-168/1000))\,; \tag{2}$$

which is the basis for NFDR-Th.

Weather variables enter the model in the calculation of a daily boundary condition expressed as:

$$m_{bi} = \frac{(\delta t - P)\bar{m}_e + \delta_s\, c\, P_s + \delta_R\, P_R(aP_R + b)}{\delta_t}\,; \tag{3}$$

where:

m_{bi} = daily boundary condition,
δt = averaging time equal to 24 hours,
P_R = duration of precipitation (rain) in hours (0-24),
P_s = duration of precipitation (snow) in hours (0-24),
P = $P_R + P_s$, the total duration of precipitation in hours,
δ_s = Kronecker delta indicating occurrence of snow,
δ_R = Kronecker delta indicating occurrence of rain,
a = liquid uptake coefficient (2.7 percent/hr) (Fosberg 1972),
b = liquid uptake coefficient (76 percent) (Fosberg 1972), and
c = coefficient equal to 30, representing the mean fiber saturation point under snow.

$$\bar{m}_e = \frac{m_e(T_{max}, h_{min}) + m_e(T_{min}, h_{max})}{2} \tag{4}$$

where:

$\bar{m}_e$ = average equilibrium moisture content for wood. The equilibrium moisture content functions for temperature (°F) and relative humidity (%) (Simard 1968) are:

$$m_e = 0.03229 + 0.281073\,h - 0.000578h\,T,\ h \leq 10\%, \tag{4a}$$

$$m_e = 2.22749 + 0.160107\,h - 0.014784\,T,\ 10\% < h \leq 50\%, \text{ and} \tag{4b}$$

$$m_e = 21.0606 + 0.005565\,h^2 - 0.00035h\,T - 0.483199\,h,\ h > 50\%; \tag{4c}$$

T_{max} = maximum 24-hour temperature;
T_{min} = minimum 24-hour temperature;
h_{max} = maximum 24-hour humidity; and
h_{min} = minimum 24-hour humidity.

The 7-day average boundary condition is:

$$m_b = \frac{1}{7} \sum_{i=1}^{7} m_{bi} \; . \qquad (5)$$

The NFDR-Th, defined by equations 1-5, was compared with the moisture content of western redcedar logs 6 inches in diameter and located on racks in clearcut units within Priest River Experimental Forest, northern Idaho (Brackebusch 1975). A correlation coefficient of 0.78 was reported (Fosberg and others 1981).

Methods

Fuel Moisture Samples

In 1979, fuel moisture samples were collected and processed for evaluating and adjusting the NFDR-Th. Samples were collected from two 2.5-acre sample plots: one in an old-growth clearcut unit and one in a nearby shelterwood unit (20 stems/acre). Both units were in the Mount Baker-Snoqualmie National Forest in western Washington (figs. 1, 2, 3). Aspect (south-southwest), slope (less than 20 percent), and elevation (2,300 feet) were similar for both units. Woody fuels consisted of mixed Douglas-fir, western hemlock, and western redcedar.

Every 7 to 10 days between May and November, fuel moisture samples were collected. Twenty randomly chosen logs 3 to 9 inches in diameter were sampled from each plot. The logs were not sampled on days when water was present on their surface. A single cross section was removed from each log at least 2 feet from the end. The entire piece was sectioned, then sealed into a 1-pint, polypropylene, screw-cap bottle capable of withstanding an autoclave. Samples were weighed to an accuracy of 0.01 gram and placed into a laminar-flow hot-air oven set at 217 °F for a minimum of 48 hours. When removed from the oven, the samples were reweighed to determine a dry weight. Moisture loss was expressed as a percentage of dry weight.

Weather Monitoring and NFDR-Th Computation

An onsite weather station equipped with a hygrothermograph and rain gauge capable of weighing and recording provided daily maximum and minimum relative humidities and temperatures, and duration of precipitation for daily computation of NFDR-Th.

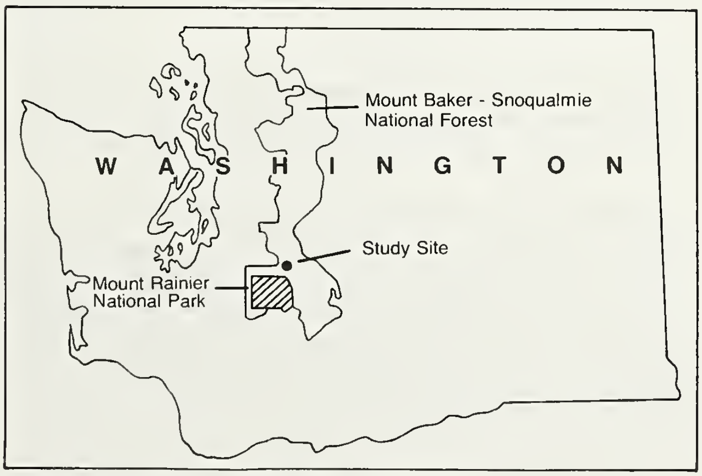

Figure 1.—Location of study sites.

Figure 2.—Partial-cut unit.

Figure 3.—Clearcut unit.

Results

Weather

Between May 1 and November 15, the weather consisted of extended dry periods intermixed with periods of precipitation (fig. 4), ideal for observing several drying and wetting cycles of the dead, woody fuels.

Measured Fuel Moisture Contents

The mean moisture content (n = 20) of the 3- to 9-inch fuels decreased gradually from an initial high of 41 percent (fig. 4). Two minor increases occurred in June and one in early July because of several days of precipitation. Beginning July 13, a 32-day period of dry weather caused moisture contents to drop to 27 percent in the partial cut unit and 25 percent in the clearcut. During the rest of this sample period, fuel moisture contents fluctuated up and down in response to periods of rain and dry weather.

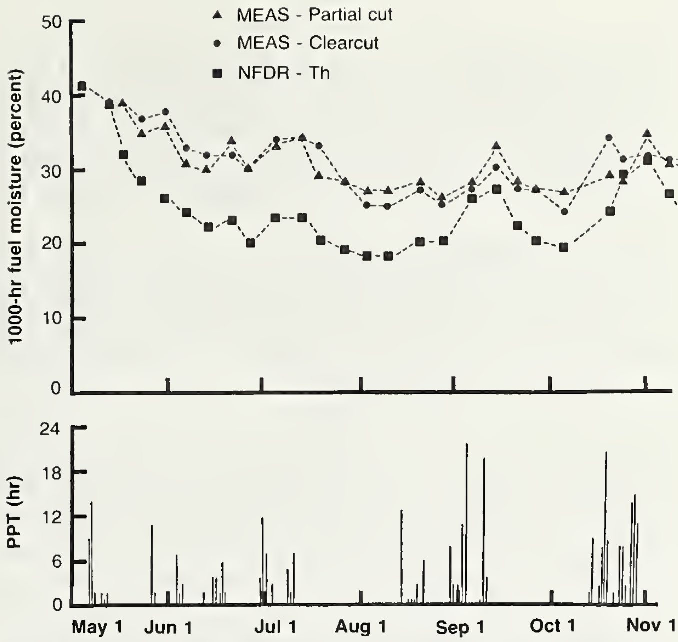

Figure 4.—Changes in fuel moistures, measured (MEAS) in partial cut and in clearcut units, fuel moistures calculated by NFDR-Th, and precipitation (PPT) duration. A moisture content initially measured at 41 percent was used as the starting value.

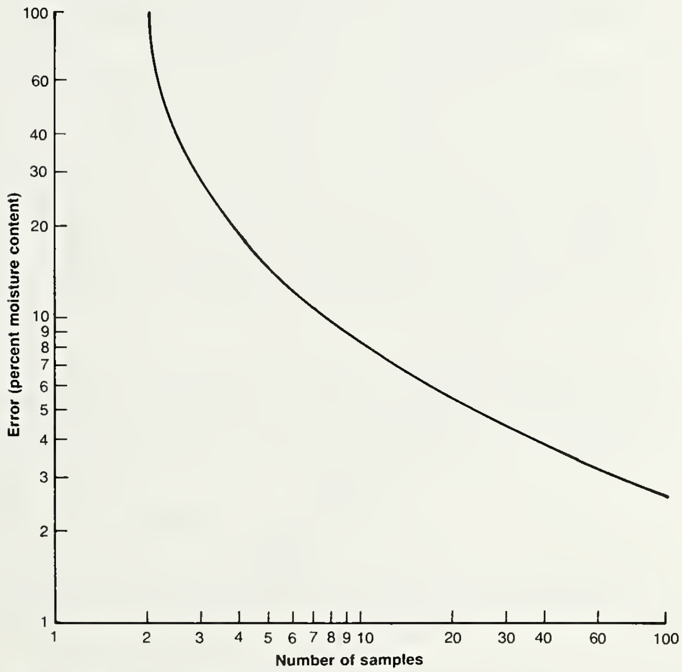

Figure 5.—Number of 1000-hour fuel moisture samples needed to achieve acceptable error.

On a given day, moisture content varied considerably between logs. Averaged over the 27 sampling periods, the standard deviation of moisture content was 12 percent in the clearcut unit and 11 percent in the partial cut unit. Because 20 samples were collected each week from each unit, the sample mean error was ±5 percent at the 95-percent confidence level (Freese 1974) (fig. 5). Sandberg and Ottmar's (1983) diameter reduction algorithm requires a fuel moisture error less than or equal to ±5 percent.

The fuel moisture contents measured during the sampling period averaged 31.1 percent in the partial cut unit (standard error of the mean 2.6 percent) and 31.2 percent in the clearcut unit (standard error of the mean 2.9 percent). The canopy cover of the partial cut unit appears to have had a minor influence on the fuel moisture content of large timelag fuels during this study.

NFDR-Th Calculations

Two differences were noted when comparing the measured fuel moisture values to the values calculated for the same fuels by NFDR-Th. First, the NFDR-Th model underpredicted moisture values by an average of 7 percent, ranging between 0 and −11 percent. Second, the NFDR-Th model overpredicted the rate of change in the drying cycles.

Measured fuel moistures were then separated by species and compared to the NFDR-Th values. The model underpredicted the Douglas-fir and western hemlock samples (fig. 6) but closely represented western redcedar logs (fig. 7). Fosberg and others (1981) developed the model's internal coefficients for ponderosa pine and tested the NFDR-Th against western redcedar. Western redcedar logs tend to have one of the lowest fuel moistures in a unit. This "worst-case" predictive approach is appropriate for the NFDR-Th model's intended purpose of rating fire danger; however, for planning prescribed fire, estimating fuel consumption, and anticipating fire effects, the forest manager requires a model that more accurately predicts an average unit fuel moisture content. NFDR-Th must be adjusted to account for Douglas-fir and western hemlock fuels, which compose a majority of the logging slash in western Washington and western Oregon.

Discussion

NFDR-Th Adjustment

The tendency of NFDR-Th to underpredict the average fuel moisture content of a unit is related to several terms in the model, one of which is the equilibrium moisture content (m_e) as defined by the instantaneous temperature and humidity (USDA Forest Service 1974). Because the numbers are averages for all species of wood without bark, they may mask the true drying effect influenced by species and other natural physical characteristics (Fosberg 1971). An adjusted m_e improves the NFDR-Th for use in Douglas-fir and western hemlock logging slash common to western Washington and western Oregon.

We rearranged terms in the basic 1000-hour fuel moisture model (eq. 2) to solve for the 7-day average boundary condition (m_b). Because m_b is defined in terms of the equilibrium moisture content during a 7-day rainless period, the boundary condition equation becomes a formula for equilibrium moisture content:

$$m_b = \overline{m}_{e7} = 3.26(m - m_o) + m_o. \tag{6}$$

Consequently, an adjustment factor can be calculated through analysis of measured and calculated fuel moisture contents that are preceded by dry weather.

Seven days of dry weather preceded 13 of the 27 sampling periods during our study. This enabled average equilibrium moisture content ($\overline{m}_{e7}$) to be calculated for 13 measured and NFDR-Th fuel moisture contents (table 1). By totaling the values for the measured moisture content and those for the calculated moisture content, we formulated a ratio. The resultant adjustment factor, using the environmental coefficient (ζ) = 0.82, was 325/203 or 1.60 times the value of equilibrium moisture content computed from the NFDR-Th predictive model.

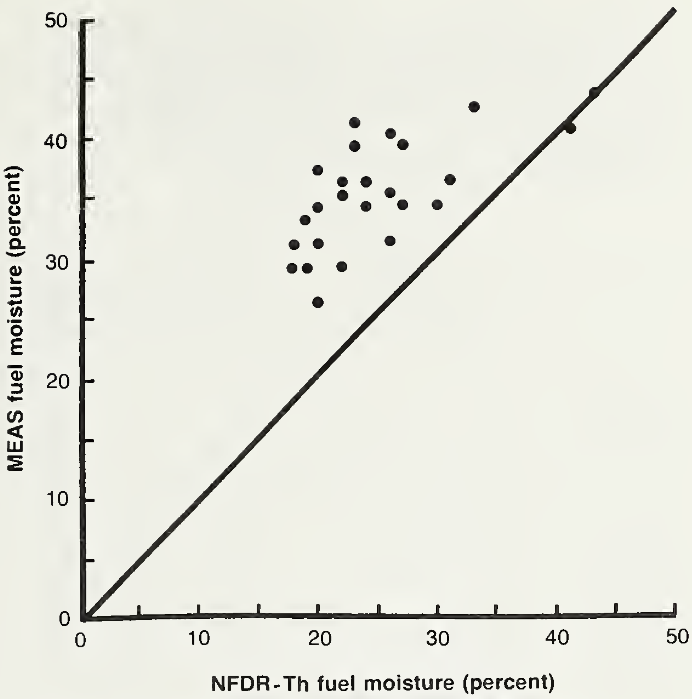

Figure 6.—Moisture values measured (MEAS) in samples of Douglas-fir and western hemlock versus values calculated by NFDR-Th. A moisture content initially measured at 43 percent was used as the starting value for NFDR-Th. The solid line indicates a perfect fit.

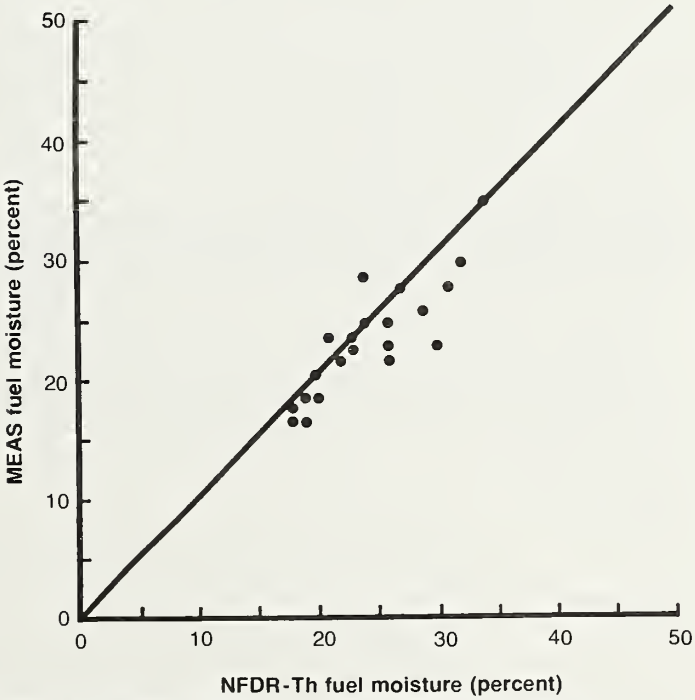

Figure 7.—Moisture values measured (MEAS) in samples of western redcedar versus values calculated by NFDR-Th. A moisture content initially measured at 34 percent was used as the starting value for NFDR-Th. The solid line indicates a perfect fit.

Table 1—Initial (m_o) and final (m) fuel moistures, and average equilibrium moisture content ($\overline{m}_{e7}$) computed from moisture contents measured and those calculated by NFDR-Th for 1000-hour timelag fuels during 13 sampling periods preceded by 7 days of dry weather

(In percent)

Date, 1979	Moisture content			Moisture content calculated by NFDR-Th		
	m_o	m	m_{e7}	m_o	m	m_{e7}
05-16	39	39	39	39	32	16
05-22	39	36	29	32	29	22
06-14	32	31	29	29	27	18
06-27	32	30	25	26	24	15
07-19	33	31	24	25	23	14
07-26	31	28	21	23	22	17
08-02	28	26	21	22	21	16
08-09	26	25	23	21	20	15
08-27	27	25	20	21	21	21
09-21	32	27	16	25	23	14
10-03	27	26	24	21	19	10
11-09	33	31	26	28	25	11
11-15	31	30	28	25	23	14
Total			325			203

Because the environmental coefficient (ζ) may vary with species and environmental condition, an optimal combination of ζ and an adjustment factor for equilibrium moisture content will exist. To test for this optimal combination, we varied ζ from 0.5 to 1.0, with an adjustment factor for equilibrium moisture content calculated for each value tested. An environmental coefficient of 0.97 and an adjustment factor of 1.4 were shown by the hypothesized variance test (Freese 1960) to best calculate the measured values (± 3 percent at the 95-percent confidence interval, fig. 8). A final comparison of NFDR-Th and ADJ-Th is:

NFDR-Th:

$$m = m_o + (m_b - m_o)(1 - 0.82\ \exp(-168/1000))\ ;$$

ADJ-Th:

$$m = m_o + (m_b - m_o)(1 - 0.97\ \exp(-168/1000))\ ;$$

where the daily equilibrium moisture content (eq. 4) is adjusted by a factor of 1.4.

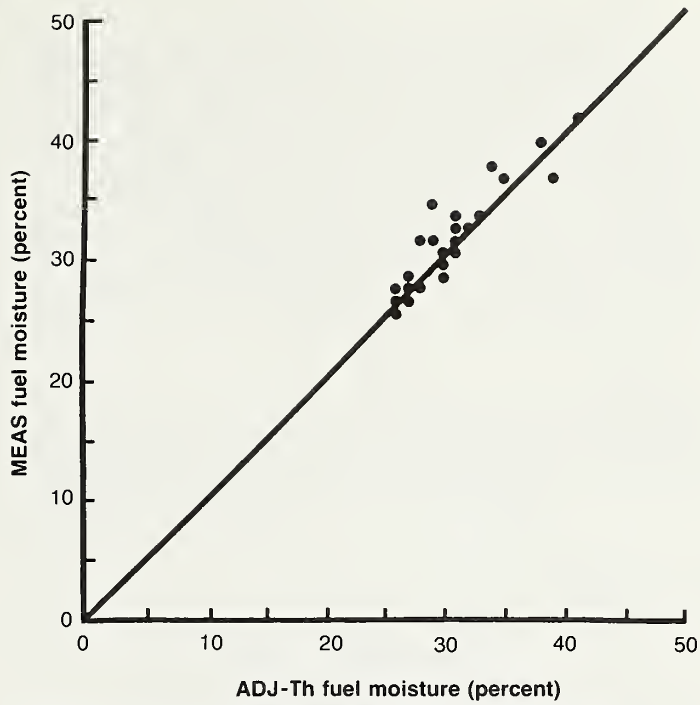

Figure 8.—Moisture values measured (MEAS) versus those calculated by ADJ-Th. The solid line indicates a perfect fit.

ADJ-Th Evaluation

Measured fuel moisture contents from seven partial-cut units and eight clearcut units located in western Washington and western Oregon were used to test the ADJ-Th. Weather data used to calculate ADJ-Th was obtained from onsite fire-weather stations. The seasonal starting value was assumed to be 40 percent, a reasonable late-spring figure based on fuel moisture sampling in 1979, 1980, and 1981. The ADJ-Th algorithm predicted the average unit fuel moisture content within ±4 percent at the 95-percent confidence level, with a range between −4 and +5 percent (fig. 9). The NFDR-Th underpredicted these average unit moisture contents by an average of 11 percent, with a range between −5 and −20 percent (table 2). The ADJ-Th has not been tested on sites with long-needled slash.

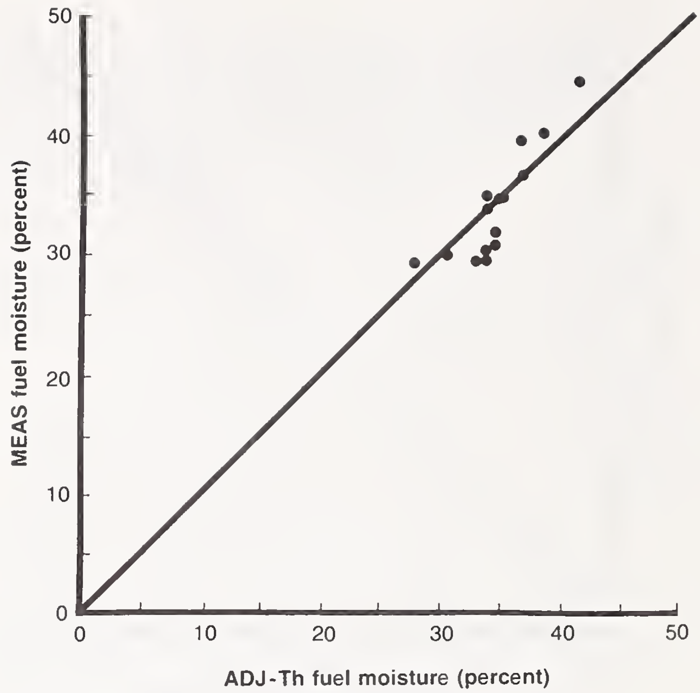

Figure 9.—Moisture values measured (MEAS) in 15 units logged in western Washington and western Oregon and values calculated by ADJ-Th. Weather data were collected from onsite weather stations. The solid line indicates a perfect fit.

Table 2—Fuel moisture contents measured (MEAS), calculated by NFDR-Th, and calculated by ADJ-Th for 1000-hour timelag fuels in 7 partial-cut and 8 clearcut units in western Washington and western Oregon

				Moisture content[1]				
Name of unit	National Forest	Date of sampling	Number of samples	MEAS	NFDR-Th[2]	Difference from MEAS	ADJ-Th[2]	Difference from MEAS
				Percent				
Partial cut:								
Quentin	Willamette	06-08-78	4	39	30	- 9	37	-2
Bow Sky	Mount Hood	06-08-78	4	44	24	-20	40	-4
Suntop I	Mount Baker-Snoqualmie	06-20-78	4	40	28	-12	37	-3
Andy I	Mount Baker-Snoqualmie	06-28-78	4	37	24	-13	37	0
Timber Butte	Willamette	06-28-78	4	35	23	-12	34	-1
Suntop II	Mount Baker-Snoqualmie	07-12-78	5	33	23	-10	33	0
Pamelia II	Willamette	07-30-78	8	29	17	-12	28	-1
Clearcut:								
Green Mountain-2	Willamette	07-13-81	35	32	23	- 9	35	+3
Green Mountain-3	Willamette	07-14-81	33	30	23	- 7	34	+4
Joule	Willamette	07-23-82	32	29	24	- 5	33	+4
Blackeye 2	Mount Hood	05-26-83	33	29	24	- 5	34	+5
Blackeye 20	Mount Hood	05-26-83	29	34	24	-10	34	0
Blackeye 3	Mount Hood	05-26-83	39	31	24	- 7	34	+3
Blackeye 30	Mount Hood	05-26-83	36	34	24	-10	34	0
Blackeye 1	Mount Hood	06-08-83	35	30	22	- 8	31	+1

[1] Seasonal starting value was assumed to be 40 percent.

[2] Weather data used to calculate NFDR-Th and ADJ-Th were obtained from onsite weather stations.

Offsite Weather Stations

Measured fuel moisture contents from 9 partial cut units and 21 clearcut units in western Washington and western Oregon were compared with ADJ-Th fuel moisture contents calculated from data recorded by offsite weather stations. These existing fire-weather stations were identified by local managers as being most likely to represent onsite conditions. When we used the hypothesized variance test (Freese 1960), ADJ-Th predicted fuel moisture contents within the ±5 percent error acceptable for estimating fuel reduction (table 3, fig. 10). This evidence suggests that current fire-weather stations provide adequate data for operation of the 1000-hour fuel moisture model.

Table 3—Fuel moisture contents measured (MEAS) and calculated by ADJ-Th for 1000-hour timelag fuels in 9 partial cut and 21 clearcut units in western Washington and western Oregon

Name of unit	National Forest	Date of sampling	Number of samples	Moisture content[1/] MEAS	ADJ-Th[2/]	Difference from MEAS
				- - - - - Percent	- - - - -	
Partial cut:						
Humpy I	Rogue	08-31-77	2	15	19	+4
Humpy II	Rogue	09-17-77	2	16	19	+3
Quentin	Willamette	06-08-78	4	39	35	-4
Bow Sky	Mount Hood	06-08-78	4	34	32	-2
Suntop I	Mount Baker-Snoqualmie	06-20-78	4	40	37	-3
Andy I	Mount Baker-Snoqualmie	06-28-78	4	37	37	0
Timber Butte	Willamette	06-28-78	4	35	34	-1
Suntop II	Mount Baker-Snoqualmie	07-12-78	5	33	34	+1
Pamelia II	Willamette	07-30-78	8	29	28	-1
Clearcut:						
Lower Till	Mount Hood	06-30-80	14	33	36	+3
Upper Till	Mount Hood	06-30-80	14	33	36	+3
Sedge	Mount Hood	07-01-80	11	40	42	+2
N-84	Olympic	08-23-80	8	25	27	+2
Cobble	Mount Hood	08-28-80	22	31	29	-2
C-150	Olympic	09-10-80	13	26	29	+3
Collawash	Mount Hood	09-17-80	10	24	25	+1
Agate	Mount Hood	06-28-81	21	37	36	-1
Green Mt. 2	Willamette	07-13-81	35	32	35	+3
Green Mt. 3	Willamette	07-14-81	33	30	34	+4
Ericson A	Siuslaw	08-06-81	37	30	33	+3
Ericson C	Siuslaw	08-06-81	34	38	33	-5
French Creek[3/]	Umpqua	10-28-81	39	26	26	0
North Slope #7[3/]	Rogue	07-13-83	23	34	30	-4
North Slope #8[3/]	Rogue	07-14-83	19	37	30	-7
North Slope #6[3/]	Rogue	07-15-83	24	33	30	-3
Cataract[3/]	Siuslaw	08-18-83	12	29	36	+7
Maria[3/]	Siuslaw	08-21-83	17	31	36	+5
Cataract Hold[3/]	Siuslaw	09-17-83	15	32	36	+4
Maria Hold[3/]	Siuslaw	09-21-83	16	37	36	-1
Yoncalla[3/]	Siuslaw	09-23-83	14	32	33	+1

[1/]Seasonal starting value was assumed to be 40 percent.

[2/]Weather data used to calculate ADJ-Th were obtained from offsite weather stations representing onsite conditions.

[3/]Data used to calculate ADJ-Th were obtained from Remote Automatic Weather Station (RAWS).

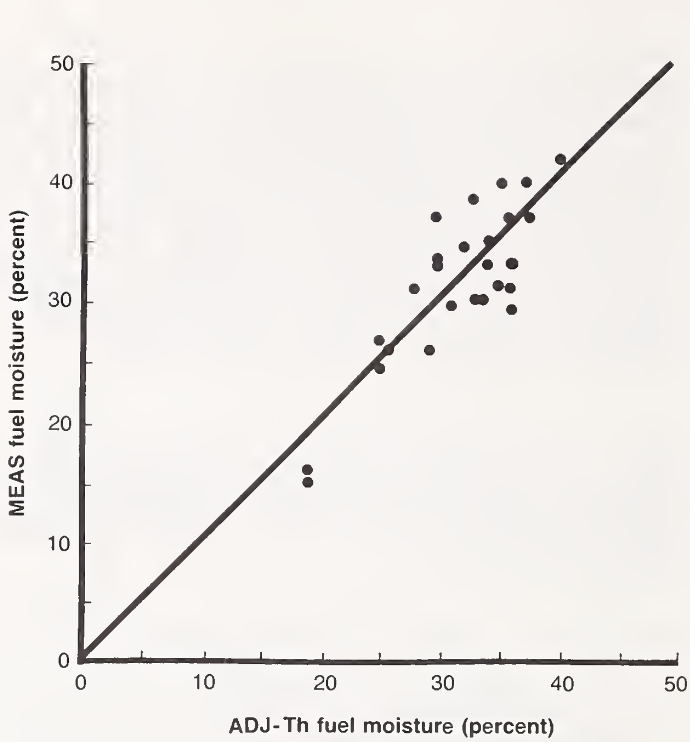

Figure 10.—Moisture values measured (MEAS) from 30 units logged in western Washington and western Oregon and values calculated by ADJ-Th. Weather data were collected from the offsite weather stations representing onsite conditions. The solid line indicates a perfect fit.

Application

The ADJ-Th moisture model replaces the need for direct fuel moisture measurements to determine an average unit fuel moisture. The model allows fire managers to accurately calculate an average unit fuel moisture content from weather variables for estimating fuel reduction. By assuming daily maximum and minimum relative humidities and temperatures and no precipitation, the forest manager can project fuel moisture and thereby determine the earliest date when burning can be prescribed for a unit.[3/]

Manually Calculating the ADJ-Th

A nomogram for manually calculating the ADJ-Th has been produced by Bob Burgan of the USDA Forest Service, Intermountain Forest and Range Experiment Station (appendix). The format and operation are identical to the 1000-hour fuel moisture nomogram presented by Burgan and others (1977). This nomogram will enable forest managers to calculate a representative 1000-hour fuel moisture content for logging slash in western Washington and western Oregon by using two weather variables: 24-hour average relative humidity and 24-hour precipitation duration. The system has been simplified to facilitate manual calculations. Hence, the manually calculated values will not match perfectly with those produced by the computer model, but the error is minimal (Burgan and others 1977).

[3/]Peterson, Janice L. Using NFDRS-predicted 1000-hour as a daily management tool. Manuscript in preparation.

Acknowledgment

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Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters, or 0.3048 meter
1 acre = 0.4047 hectare
1 pint = 0.5506 liter (liquid)
1 gram = 0.0353 ounce
°F = 1.8 (°C) +32

Literature Cited

Brackebusch, Arthur P. Gain and loss of moisture in large forest fuels. Res. Pap. INT-173. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1975.** 50 p.

Burgan, Robert E.; Cohen, Jack D.; Deeming, John E. Manually calculating fire-danger ratings—1978 National Fire Danger Rating System. Gen. Tech. Rep. INT-40. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1977.** 49 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. The National Fire-Danger Rating System—1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1977.** 63 p.

Fosberg, Michael A. Moisture content calculations for the 100-hour timelag fuel in fire danger rating. Res. Note RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; **1971.** 7 p.

Fosberg, Michael A. Theory of precipitation effects on dead cylindrical fuels. Forest Science. 18: 98-108; **1972.**

Fosberg, Michael A.; Rothermel, Richard C.; Andrews, Patricia L. Moisture content calculations for 1000-hour timelag fuels. Forest Science. 27: 19-26; **1981.**

Freese, Frank. Elementary statistical methods for foresters. Agric. Handb. No. 317. Washington, DC: U.S. Department of Agriculture; **1974.** 87 p.

Freese, Frank. Testing accuracy. Forest Science. 6(2): 139-145; **1960.**

Ottmar, Roger D. The evaluation and adjustment of large-fuel moisture models from the National Fire-Danger Rating System for prescribed fire planning. Seattle, WA: University of Washington; **1980.** 126 p. M. S. thesis.

Sandberg, D. V.; Ottmar, R. D. Slash burning and fuel consumption in the Douglas-fir subregion. In: Proceedings, 7th AMS/SAF conference on fire and forest meteorology; 1983 April 25-29; Fort Collins, CO. Boston, MA: American Meteorological Society; **1983:** 90-93.

Simard, Albert J. The moisture content of forest fuels—I: A review of the basic concepts. Ottawa, ON: Forest Fire Research Institute; **1968;** Inform. Rep. FF-X-14. 47 p.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Wood handbook: wood as an engineering material. Agric. Handb. No. 72, rev. Washington, DC: U.S. Department of Agriculture; **1974.**

Appendix

Using the ADJ-Th Nomograms[1]

1. Determine the average relative humidity and number of hours precipitation fell during a 24-hour period.

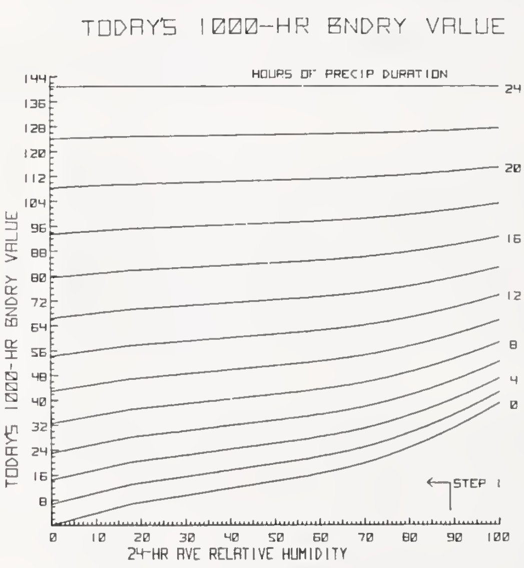
2. Using Nomogram 1, enter the 24-HR AVE RELATIVE HUMIDITY on the X-axis and draw a vertical line to the appropriate curve for precipitation duration. Draw a horizontal line left across the nomogram from that point to determine TODAY'S 1000-HR BNDRY VALUE.

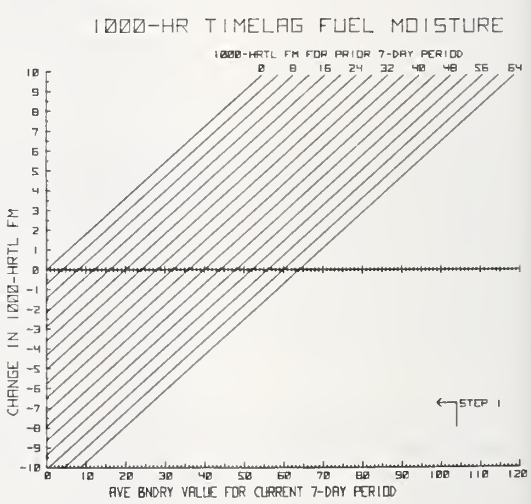
3. Determine TODAY'S 1000-HR BNDRY VALUE for 7 days and calculate an average.

4. Using nomograph 2, enter the AVE BNDRY VALUE FOR CURRENT 7-DAY PERIOD on the X-axis and draw a vertical line to the appropriate 1000-HRTL FM FOR PRIOR 7-DAY PERIOD. Draw a horizontal line left across the nomogram from that point to determine the CHANGE IN 1000-HRTL FM.

5. Add the CHANGE IN 1000-HRTL FM to the 1000-HRTL FM FOR PRIOR 7-DAY PERIOD to determine the current value.

6. The nomogram starting value can be determined from fuel moisture samples collected in the field or by using an approximate spring season value of 40 percent.





[1] Refer to Burgan and others (1977) for more detailed instructions.

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Ottmar, Roger D.; Sandberg, David V. Calculating moisture content for 1000-hour timelag fuels in western Washington and western Oregon. Res. Pap. PNW-336. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 16 p.

A predictive model is presented to calculate moisture content of 1000-hour timelag fuels in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg) logging slash in western Washington and western Oregon. The model is a modification of the 1000-hour fuel moisture model of the National Fire-Danger Rating System and requires daily measurements of precipitation duration, maximum and minimum relative humidities, and maximum and minimum temperatures. Comparison of measured and calculated fuel moisture contents showed good agreement. The model allows managers to accurately calculate fuel moisture values from weather variables for fuel reduction estimates. Current fire-weather stations provide adequate weather data for satisfactory operation of the 1000-hour fuel moisture model.

Keywords: Fuel moisture content, fire danger rating.

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